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Title: The Influence of In-Season Training Loads on Injury Risk in Professional Rugby Union

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ABSTRACT

Purpose: To explore the association between in-season training load measures and injury risk in professional Rugby Union players. **Methods** This was a one-season prospective cohort study of 173 Professional Rugby Union players from four English Premiership teams. Training load (duration x session-RPE) and time-loss injuries were recorded for all players for all pitch and gym based sessions. Generalised estimating equations were used to model the association between in-season training load measures and injury risk in the subsequent week. **Results:** Injury risk increased linearly with one-week loads and week-to-week changes in loads, with a 2 standard deviation (SD) increase in these variables (1245 AU and 1069 AU, respectively) associated with odds ratios of 1.68 (95% CI 1.05-2.68) and 1.58 (95% CI: 0.98-2.54). When compared with the reference group (<3684 AU), a significant non-linear effect was evident for four-week cumulative loads, with a likely beneficial reduction in injury risk associated with intermediate loads of 5932 to 8651 AU (OR: 0.55, 95% CI: 0.22-1.38) (this range equates to around four weeks of average in-season training load), and a likely harmful effect evident for higher loads of >8651 AU (OR: 1.39, 95% CI: 0.98-1.98). **Conclusions:** Players had an increased risk of injury if they had high one-week cumulative loads (1245 AU), or large week-to-week changes in load (1069 AU). In addition, a 'U-shaped' relationship was observed for four-week cumulative loads, with an apparent increase in risk associated with higher loads (>8651 AU). These measures should therefore be monitored to inform injury risk reduction strategies.

INTRODUCTION

The aim of training is to optimise performance through the mastery of sport specific skills and advancing physical conditioning. However, the process of applying appropriate training loads (a product of training intensity, volume/duration and frequency) is a constant challenge for coaches, particularly in the context of season-long team sports[1]. Whilst increasing training loads is generally thought to improve athletic performance[2], it may also increase player fatigue and injury risk[3]. Injury impacts on individual's ability to train and compete, and higher injury burden has been associated with poorer team success in professional football cohorts[4,5]. As such, the prescription of appropriate training loads requires a careful consideration of the positive (fitness and skill development) and negative (fatigue and injury risk) response[6].

Many studies have looked at the training load-performance relationship in sport[1,2,7], but a far smaller number have investigated the association between training loads and injury in contact sports, especially within an elite population. Previous studies[3,8-10] have shown that a reduction in training load in-season resulted in a reduction in the incidence rate of injuries. One of these studies[9] suggested that a player's threshold (the amount of training load that could be sustained by the player before an injury occurred) decreased during the season, potentially as players became fatigued when compared to pre-season thresholds. Higher weekly and two weekly cumulative loads and absolute week-to-week changes in load have been associated with an increased risk of injury in Australian Football[11]. Players who experienced a change in previous to current week load of >1250 AU (~75% change) were 2.58 times more likely to be injured in comparison with the reference group of a <250 AU (~15% change) . Furthermore, elevated three-weekly cumulative loads derived from Global Positioning Systems (GPS) measurements were also associated with an increased risk of injury in this population[12].

A small number of studies have investigated the relationship between training volume (duration of training) and injury risk in Rugby Union[13,14]. Brooks and colleagues[13] found that the mean training volumes for pre-season and in-season were 9.2 and 6.3 hours respectively with more time spent on conditioning in pre-season and skills training in season[15]. The lowest number of days lost due to injuries occurred during weeks of intermediate training volume (6.2 - 9.1 hours per week). A higher training volume (> 9.1 hours per week) did not increase injury incidence rates but did increase the severity of match injuries. In addition, Viljoen and colleagues[14] recorded training volumes within a professional team over a three year period and concluded that a reduction in training volume over three seasons was associated with slight reduction to in-season injury rates. However, it was noted that the team's league position also changed from 3rd to 7th (2002-2004) and thus, did not recommend reducing training volumes too much as the players may no longer be exposed to the required training stimulus in order to be able to compete effectively during matches.

It is likely that the training load-injury relationship for each sport is unique, given the different periodisation patterns and physical demands of training and match-play imposed upon players. To date, training load has not been investigated as a modifiable risk factor for injury in Rugby Union. Advances in our understanding of this area will enable coaching staff to have more confidence that the training loads that they prescribe do not significantly increase a player's risk of injury. Accordingly, the purpose of the present study was to explore the association between selected training load measures and injury risk in professional Rugby Union players.

METHODS

Participants

This was a prospective cohort study of Professional Rugby Union players registered in the first team squad of four teams competing at the highest level of Rugby Union in England (English Premiership). Data were collected for 173 players (team A = 43 players, team B = 41 players, team C = 46 players, team D = 43 players) over one season (2013/14). The study was approved by the Research Ethics Approval Committee for Health at the University of Bath and written informed consent was obtained from each participant.

Procedures

All time-loss injuries were recorded by the medical personnel at each team using the Rugby Squad medical database (The Sports Office UK, 2011). A modified version of the Orchard sports injury classification system OSICS[16] was embedded within the medical system and was used to code each injury diagnosis. Reported time-loss injuries were included in the study if they occurred in training or 1st or 2nd team competitive matches and if they met the 24-hour time-loss definition[17].

The intensity of all training sessions (including rehabilitation sessions) were estimated using the modified Borg CR-10 RPE (Rate of Perceived Exertion) scale[18], with ratings obtained from each individual player within 30 minutes after the end of each training session[19]. A member of each club's strength and conditioning staff was allocated to be in charge of the club's data collection, they were then briefed on the intensity scale and all clubs were given the same scale to use during the season. Each player had the scale explained to them by their strength and conditioning coach before the start of the season and players were asked to report their RPE for each session confidentially to the strength and conditioning coach without knowledge of other players' ratings. Session RPE in arbitrary units (AU) for each player was then derived by multiplying RPE and session duration/volume (min). Session RPE has previously been shown to be a valid method for estimating exercise intensity[20] and returned positive correlations of 0.89 and 0.86 with training heart rate and training blood lactate concentrations, respectively, during typical Rugby League training activities[10]. Thus, the session RPE method was an inexpensive, simple and highly practical approach that allowed valid and reliable measures of each player's internal response to both pitch-based and gym-based training sessions[21]. These data were collated and sent to the project leader on a monthly basis by strength and conditioning staff.

The competitive season was split into two distinct phases for descriptive purposes, namely: 'pre-season' (between 8-11 weeks dependent on when each club commenced their season) and in-season (36 weeks). The in-season phase was then split into 'early-competition'(first 18 weeks of the competitive season) and 'late-competition'(last 18 weeks of the competitive season), to ascertain if there were any differences in training loads between these phases as differences may exist in training objectives between early and late in-season competition. [9]. In addition to weekly training load (sum over each 7-day period, commencing Monday of: session intensity [RPE] x session duration [mins]), a number of other training load measures were derived based on previous studies: a) cumulative two, three and four weekly loads calculated by the sum of the previous weeks' training loads[11]; b) week-to-week change in loads (absolute change in a players current load from that of the previous week)[11]; c) weekly training monotony (weekly mean/standard deviation)[22]; d) weekly training strain (weekly training load x training monotony)[22]; and e) training stress balance (a player's acute (one week) workload divided by their chronic (four week rolling average) workload)[23].

Statistical Analysis

Data were analysed in SPSS Version 22.0 (IBM Corporation, New York, USA). A two-way (Phase × Team) mixed analysis of variance (ANOVA) was used to identify differences in training loads between phases of the season, and between teams. Generalised estimating equations were used to model the association between in-season (early and late competition phases combined) training load measures and injury in the subsequent week, using a binary distribution, logit link function, first-order autoregressive (AR1) working correlation structure, and offset for players' individual match exposure. Based on the data supplied by one team in this study, our observations suggest there is very little variation in reported RPE for matches (i.e. the vast majority of players reported 9-10), and so match exposure was the key distinguishing element between players. Individual match exposure was therefore accounted for, but did not contribute to training load values. This model was selected for its ability to account for intra-player and intra-team cluster effects[24]. If assessment of a quadratic trend between the training load measure and injury risk was significant ($P \leq 0.05$), training loads were sorted from smallest to largest and the measure was split into quartiles for analysis, with the lowest load range being the reference group to enable us to compare the risk of injury at intermediate, higher intermediate and high loads compared with low loads. Otherwise, linear effects for continuous predictor variables were evaluated as the change in injury risk (Odds Ratio [OR]) associated with a two standard deviation increase in the training load measure[25]. Correlation coefficients between the training load measures, alongside Variance Inflation Factors (VIF), were used to detect multicollinearity between the predictor variables. A VIF of ≥10 was deemed indicative of substantial multicollinearity[26].

Magnitude-based inferences were used to provide an interpretation of the real-world relevance of the outcome[27]. The smallest worthwhile increase in risk (i.e. harmful effect) for time-loss injuries was an odds ratio of 1.11, and the smallest worthwhile decrease in risk (i.e. beneficial effect) was 0.90[28]. An effect was deemed unclear if the chance that the true value was beneficial was >25%, with odds of benefit relative to odds of harm (odds ratio) of <66 (or vice versa). Otherwise, the effect was deemed clear, and was qualified with a probabilistic term using the following scale : <0.5%, most unlikely; 0.5-5%, very unlikely; 5-25%, unlikely; 25-75%, possible; 75-95%, likely; 95-99.5%, very likely; >99.5%, most likely [29].

RESULTS

In total, 465 time-loss injuries (303 match, 162 training) were reported across the 4 teams during the season. Overall, match injury incidence was 101.7/1000 hours, 95% CI: 90.9-113.8) and training injury incidence was (3.3/1000 hours, 95% CI: 2.8-3.8). The total match and training volumes reported during the season were 2980 hours and 51653 hours respectively.

The two-way mixed ANOVA showed significant (P<0.01) effects for Team, Phase, and Phase × Team. Average weekly training loads decreased from pre-season (2175 ± 380 AU), to in-season, with no significant differences between early-competition (1522 ± 203 AU) and late-competition (1581 ± 317 AU) phases (figure 1).

>>>>>>>>>>>>>>>>>>>>Figure 1 <<<<<<<<<<<<<<<<<<

Weekly training strain and two- and three-weekly cumulative loads displayed substantial multicollinearity with other training load measures, and so were excluded from the analysis. The small number of injuries (n=24) and match exposure (200 hours) during the pre-season period in this study produced unstable estimates (i.e. large standard errors) thus; the pre-season loading data are only presented for information and were not included in the model. As there was no significant difference in the training loads between in-season early and late competition phases, all in-season loads were included in the model. During the in-season phase, risk of injury in the subsequent week increased linearly with one-week loads and absolute change in loads, with a two standard deviation rise in these variables (1245 AU and 1069 AU, respectively) being associated with an increase in the odds of injury of 1.68 (95% CI 1.05-2.68) and 1.58 (95% CI: 0.98-2.54), respectively (Table 1). The change in injury risk associated with a two standard deviation increase in training monotony (0.39AU) and training stress balance (172%) was unclear. A significant non-linear effect was evident for four-week cumulative loads (Figure 2), with a likely beneficial reduction in injury risk associated with ‘high intermediate’ loads of 5932 to 8651 AU (OR: 0.55, 95% CI: 0.22-1.38), and a likely harmful effect evident for ‘high’ loads of >8651 AU (OR: 1.39, 95% CI: 0.98-1.98) compared with the reference group of ‘low’ loads (<3684 AU).

>>>>>>>>>>>>>>>>>>>Table 1 <<<<<<<<<<<<<<<<<<<

>>>>>>>>>>>>>>>>>>>Figure 2<<<<<<<<<<<<<<<<<<<<

DISCUSSION

This is the first study to investigate the association between training load measures and injury risk in professional Rugby Union players. The results of this study suggest that a positive linear relationship exists between both weekly training load and absolute week-to-week changes in load and subsequent injury risk during the in-season phase. In addition, a ‘U-shaped’ relationship between four-week cumulative loads and injury risk was identified. These findings suggest that weekly training loads, week-to-week changes in load, and 4-week cumulative loads could be adapted by professional Rugby Union teams in order to reduce injury risk in this setting.

The mean weekly training loads described in this study were smaller than those previously described in professional Rugby Union[30] and Rugby League[3], but were similar to those observed in professional Australian Rules Football[11]. A two standard deviation (or 80% based on an average in-season week) increase of in-season weekly load (1245 AU, approximately a 4 hour increase of an average in-season training intensity [RPE=5]) was associated with around a 70% increase in injury risk in the subsequent week. This finding is consistent with the majority of previous research in contact sports[3,8,11], and may be related to the impact of fatigue and concomitant changes in neuromuscular control[31].

In agreement with the findings of Rogalski and colleagues[11] absolute changes in week-to-week loads increased the risk of injury, with an absolute change in load of 1069 AU (about 3.5 hours of average in-season training intensity during this study) associated with an approximate 60% increase in the risk of injury the following week. This is important from a practical perspective as sudden training load increases could be imposed on players who are returning to training from injury. Equally, sudden decreases in week to week load could be associated with players who have to undertake modified training regularly, often in order to manage a chronic injury. Clubs should re-integrate players (injured or otherwise) back into training in a conservative manner, whilst carefully monitoring their training load in order to prevent a high weekly change in load and ultimately reduce the risk of injury (or subsequent injury in the case of injured players). However, it is noted that in practice the consistent application of this recommendation can prove difficult as coaches typically hope that any player will be able to train without restriction with the rest of the training squad as soon as they are able to do so. Training stress balance, which expresses acute workloads (i.e. 1-week data) against chronic workloads (i.e. 4-week rolling average), may be a useful means of monitoring this aspect of loading. The association between training stress balance and injury risk in the present study was unclear, and so further data are required to confirm its utility in this setting.

Previous studies in professional contact sport have reported a positive linear relationship between cumulative loads and injury risk[11,12]. The present study is the first to present a non-linear association between cumulative training loads and injury risk, but a similar relationship has been observed previously with average weekly training volume (duration only) and injury risk in professional Rugby Union players[13]. A 'U-shaped' relationship between four-week cumulative loads and injury risk was identified. Four-week loads were associated with a decrease in the likelihood of injury in the 'high intermediate' quartile (5932 to <8651 AU) in comparison to the 'low' reference quartile (<3684 AU), however injury risk increased substantially thereafter for 'high' loads (≥8651 AU). Given that the mean in-season weekly training loads were ~1500 AU, four weeks of training would equate to ~ 6000 AU and would sit within the third quartile of four week cumulative loads. It can be reasonably assumed that the players within this quartile are likely to have been training regularly during the four week period and will have acquired an appropriate level of fitness and physical robustness, which may explain the reduction in injury risk for this group. It is likely that the training loads exhibited in the 'high intermediate' quartile group reflect a training load that best allows players to adapt to a performance training stimulus without substantially increasing injury risk[11,32]. The increase in risk associated with players in the 'high' quartile for load (>8651 AU) suggests that players are likely to have an individual range, above which they are substantially more likely to incur an injury. The pre-season training loads reported in this study (2175 ± 380) AU are around half of those previously reported in professional rugby league[3]. These low pre-season loads may have meant that players were unable to tolerate in-season training loads in the highest 4-week quartile as they had not been exposed to similar loads previously. Conversely, excessive cumulative fatigue (adaptation without sufficient recovery) may lead to a reduction in the amount of stress that tissues can cope with and thus, beyond a certain threshold of load, the risk of injury increases[33]. It is not possible to say if the increase in in-season injury risk observed in the highest quartile is due to insufficient recovery time during high cumulative loads or, if players were inadequately prepared to cope with the loads in this quartile due to the low level of pre-season training loads prescribed. It is likely that both these factors contributed to an increase in injury risk in this study.

There is a clear requirement for coaches to achieve a balance between simultaneously allowing exposure to an adequate training stimulus in order to prepare the player for the specific demands of their sport and to subsequently improve performance[2,14] whilst limiting a player's load in order to prevent injury. This is particularly important in contact sports whereby practitioners need to prepare players to be able to cope with the demand of contact events whilst managing their overall risk of contact injury. One way that this might be achieved in practice is by reducing training monotony. It has been suggested that players may be able to manage high daily training loads as long as they are dispersed between lower load training days and/or a day off during the training week[22]. The association between training monotony and injury risk in the present study was unclear, and this measure should be explored with larger samples in future studies.

PRACTICAL APPLICATIONS

This study is the first to provide an indication of how players' weekly training load is associated with injury risk in professional Rugby Union. Team coaches should monitor a player's weekly load, week-to-week changes in load and four-week cumulative load, when planning and implementing training to optimise performance whilst minimising injury risk. Given that these findings suggest that a high load and a large absolute change in load increase the risk of injury in professional Rugby Union players, trying to periodise training schedules with alternating heavy and light training weeks is not recommended (as opposed to alternating heavy and light days which requires further investigation). One way that this may be achieved in practice is for coaches to prescribe stable and consistent weekly loads throughout the season in order to prevent any spikes in acute workload. Our results also suggest that professional players may have a four-week cumulative training load limit, and that exceeding this threshold is associated with a substantial increase in injury risk. Strength and conditioning coaches should use these findings as a starting point for planning and monitoring individual player training thresholds. The physiological demands and movement patterns of different sports vary significantly and any application of these findings in other populations should be performed with caution.

LIMITATIONS

Factors in addition to training and match load are likely to impact upon an individual's injury risk, such as previous injury[34] and psychological stressors[35], and these were not accounted for in the analysis. Given that only a small number of reported injuries and match exposure was reported during the pre-season phase, these training loads were not included in the model used to investigate the association between training load measures and injury risk. The impact of this phase should be investigated in future studies. The day, week and phase of the season were reported clearly by all clubs, however, only total load values were collected rather than information pertaining to the specific type of training modality used in each session. Unfortunately, it was therefore not possible to describe the training load values of specific session types in this study. In addition, information regarding the association between training load and specific types of injury (e.g. soft tissue injuries) could not be investigated due to the sample size (and associated statistical power) available in the current study, this warrants future investigation. No meaningful conclusions could be drawn regarding training monotony or training stress balance as risk factors for injury. These load variables should be investigated in future using a more statistically powerful sample. Furthermore, whilst the session-RPE method has been proposed as an acceptable method of quantifying training load in collision sports[21], GPS measures might provide additional data regarding external total training load. In this context, some training activities (skills, wrestling, strongman and speed sessions) may be better quantified using a combination of internal- and external-load measures.

CONCLUSIONS

This study is the first to show an association between training load and risk of injury in professional Rugby Union. Players were at an increased risk of injury if they had a high one week cumulative load or a large week-to-week change in load. A ‘U-shaped’ association between four-week cumulative loads and injury risk was identified. The ‘high intermediate’ quartile of four-week cumulative load 5932 to <8651 AU (in a practical sense, the lower limit of this range equates to around four weeks of average in-season training load) would appear to be beneficial in reducing injury risk in this population. These measures should therefore be individually monitored in professional Rugby Union players, as a potential means of informing risk reduction strategies in this setting.

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Table and Figure Captions

Figure 1. Mean weekly training loads (AU) by team for each phase during the 2013-14 season with error bars showing standard deviation (e.g. four sessions of RPE=7 and 45 minute duration would produce a training load of 1260 AU).

Table 1 . Training load risk factors for injury in professional Rugby Union.

Figure 2. Four weekly cumulative training load quartiles and the likelihood of injury [%]. * denotes substantial change in injury risk in comparison with reference group (<3684 AU).

Table 1 .

Load calculation	2 SDs	Effect of 2 SD increase [Odds ratio]	95% Confidence intervals Lower	Upper	*P*-Value	Inference	% likelihood effect is beneficial | trivial | harmful
1 week cumulative load	1245 AU	1.68	1.05	2.68	0.003	Very likely harmful	0 | 1 | 99%
Absolute change (±)	1069 AU	1.58	0.98	2.54	0.06	Likely harmful	1 | 6 | 93%
Monotony	0.39	1.22	0.84	1.78	0.29	Unclear	5 | 26 | 69%
Training stress balance	172%	1.41	0.60	2.80	0.42	Unclear	15 | 14 | 71%
4 week cumulative load							
<3684 AU (reference)		1.00					
3684 to <5932 AU		0.79	0.48	1.29	0.34	Unclear	70 | 21 | 9%
5932 to <8651 AU		0.55	0.22	1.38	0.20	Likely beneficial	85 | 8 | 7%
≥8651 AU		1.39	0.98	1.98	0.06	Likely harmful	1 | 9 | 90%